AL/OE-TR-1994-0179

ARMSTRONG LABORATORY

EFFECTS OF SIMULATED SONIC BOOMS ON THE HATCHABILITY OF WHITE LEGHORN CHICKEN EGGS

Ann E. Bowles, PhD
Meredith Knobler

Hubbs-Sea World Research Institute
2595 Ingraham Street
San Diego CA 92109

Matthew D. Seddon
B. Andrew Kugler

BBN Systems and Technologies
21120 Vanowen Street
Canoga Park CA 91303

OCCUPATIONAL AND ENVIRONMENTAL HEALTH DIRECTORATE
BIOENVIRONMENTAL ENGINEERING DIVISION
2610 7th St
Wright-Patterson AFB OH 454[illegible]

June 1994

FINAL TECHNICAL REPORT FOR PERIOD APRIL TO JUNE 1994

Approved for public release; distribution is unlimited.

AIR FORCE MATERIEL COMMAND
BROOKS AIR FORCE BASE, TEXAS

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Armstrong Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22314

DISCLAIMER

This Technical Report is published as received and has not been edited by the staff of the Armstrong Laboratory.

TECHNICAL REVIEW AND APPROVAL

AL/OE-TR-1994-0179

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Council.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

ROBERT C. KULL, JR., MAJ., USAF
Chief, Noise Effects Branch

FOR THE DIRECTOR

JAMES D. MONTGOMERY, LT COL, USAF, BSC
Chief, Bioenvironmental Engineering Division
Armstrong Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1994	Final 1 April - 1 June 1994

4. TITLE AND SUBTITLE
Effects of Simulated Sonic Booms on the Hatchability of White Leghorn Chicken Eggs

5. FUNDING NUMBERS
C - F33615-89-C-0574
PE - 63723F
PR - 3037
TA - 05
WU - 06

6. AUTHOR(S) Ann E. Bowles, PhD and Meredith Knobler of Hubbs-Sea World Research Institute; and Matthew D. Sneddon and B. Andrew Kugler of BBN Systems and Technologies

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Systems Research Laboratories
2800 Indian Ripple Road
Dayton OH 45440

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Occupational & Environmental Health Directorate
Bioenvironmental Engineering Division
Human Systems Center
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7901

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/OE-TR-1994-0179

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Eggs of domestic white leghorn chickens were exposed to simulated sonic booms in the Sonic Boom Test Facility at BBN Systems and Technologies in Canoga Park CA. Two-hundred and fifty-two fertile eggs in four groups were exposed to booms with levels of 3 psf (group A), 20 psf (group B), O psf (control group C) and 30 psf (group D). Ten exposures were given daily separated by 10 sec intervals (day 2-19 of incubation). Chicks were held for four days after hatching for observation. By chance, the mean egg weight at laying of groups A and C differed from groups B and D. Differences in survivorship among the groups during incubation were explained by this difference, with survivorship significantly lower in the least exposed groups (A and C; Time series analysis, Mantel-Cox criterion; $c^2 = 5.67$; df = 1,245; $p < 0.05$). Final counts of the numbers of eggs pipped and hatched did not differ ($c^2 = 1.21$; df = 3; $p \geq 0.05$), nor did weekly weights and weight at hatching (ANOVA, $p > 0.05$). None of the exposed eggs cracked during exposure and all chicks hatched were normal. Resonance frequencies of 23 chicken eggs ranged between 468 and 1036 Hz, and of 4 quail eggs between 1274 and 1475 Hz, 6-7 octaves above the peak energy in the simulated sonic booms.

14. SUBJECT TERMS
Sonic Booms, White Leghorn Chickens, Hatchability, Resonance, Bird Eggs

15. NUMBER OF PAGES
54

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This study was prepared by personnel from the Hubbs-Sea World Research Institute (HSWRI) under the direction of Dr. Ann Bowles, Principal Investigator. The research was conducted under subcontract to BBN Systems and Technologies in Canoga Park, CA, under the supervision of B. Andrew Kugler. The work described herein is in fulfillment of Task 87N of Contract F33615-89-C-0574, which was directed by Systems Research Laboratories under prime contract to the U.S. Air Force.

ACKNOWLEDGMENTS

We thank the Aviculture Department at Sea World and Dr. J.R. Jehl, Jr. for their invaluable suggestions in the planning of this experiment. Red Wing Hatchery and CEBE Farms provided the eggs for this experiment. Technicians Sam Tomooka and Rick Howe maintained the Sonic Boom Test Facility at BBN Systems and Technologies and assisted in running the equipment during its nineteen-day term, keeping 'egg time' without regard for weekends. The Raptor Rehabilitation and Release Program in Simi Valley kindly took the chicks at the end of the experiment, where they were used in the rescue of injured wildlife.

Effects of Simulated Sonic Booms on the Hatchability of White Leghorn Chicken Eggs

1.0 INTRODUCTION

In 1969, Austin *et al.* (1970a) presented a paper at the International Ornithological Congress (IOC) in which they suggested that sonic booms could have caused a mass hatching failure of Sooty Terns (*Sterna fuscata*) on the Dry Tortugas, Florida. Although the evidence admittedly was circumstantial, the abstract of this presentation has become the most commonly-quoted evidence that sonic booms can harm wildlife. It is referenced in reviewed publications (Bell, 1972; Feare, 1976; Cottereau, 1978; Haynes, 1987), popular articles (Graham, 1979; Anonymous, 1969; Shotton, 1982), government-sponsored studies (Hinshaw *et al.,* 1970; Subcommittee on Animal Response, 1970; Fletcher and Harvey, 1971; Bender, 1977; Hurtubise *et al.,* 1978; Manuwal, 1978; Hecock and Rhoads, 1979; Dufour, 1980; Ellis, 1981; Kull and Fisher, 1986; Manci *et al.,* 1988), and many Environmental Impact Statements (EIS).

Austin *et al.* (1970b) outlined their case in a well-documented manuscript. When observers arrived in April and May of 1969 to count nests and eggs, they found normal numbers of ground-nesting Sooty Terns (originally estimated at 50,000 pairs, now known to be 25,000-40,000 pairs) and bush-nesting Brown Noddies (*Anous stolidus*; 2,500 pairs) breeding on the Dry Tortugas. Nests appeared to have normal clutches of eggs. On 23-27 May other observers found fewer chicks than expected, but adults appeared to be incubating normally. However, when Austin *et al.* arrived in mid-June to count and band fledglings, they found half the adult Sooty Terns gone and the remaining ones "markedly wild and restless." Many eggs containing partially developed embryos were abandoned. The authors banded only 242 fledglings instead of the expected 10,000-15,000. This failure was particularly startling because the Brown Noddies, nesting in bushes in the same area, fledged normal numbers of young.

To explain the cause of the failure, Austin *et al.* considered and rejected many possible natural causes of mortality, including predators, food shortages, pesticides, humans walking in the colony, and abnormal weather conditions. An unusually heavy growth of herbaceous vegetation might also have been a contributing factor.

In addition to these natural explanations, the authors discovered that personnel of Fort Jefferson National Monument on neighboring Garden Key had been disturbed by sonic booms intense enough to shatter windows during their absence. Although sonic booms were a common occurrence on the Dry Tortugas at that time, unusually intense booms were heard on 4, 8, 9, and 11 May.

In the published abstract, Austin *et al.* (1970a) were careful to state "we have no evidence that sonic booms caused physical damage to the eggs, but it is entirely possible that strong booms caused desertion." However, in their presentation and manuscript (Austin *et al.*, 1970b) they observed that physical damage by sonic booms could have caused the losses because many of the failed eggs had longitudinal hairline cracks and because the timing of the overflights agreed well with the stage of development of the failed eggs. They speculated that military jets flying at supersonic speeds had caused the damage. These observations and speculations were the source material for a number of popular articles written shortly after the conference (*e.g.*, Anonymous, 1969; Graham, 1969) and later analyses of the incident (Bell, 1972; Dufour, 1980).

After discovering the hatching failure, the Park Service asked the Navy to avoid flying over the Dry Tortugas and also arranged to have the vegetation cleared. The hatch the following year (1970) was normal, and no similar incident has occurred since (G. Woolfenden, pers. comm.).

The most compelling evidence cited by Austin *et al.* was the coincidence between the sonic booms and the egg failures. They explained the difference in success between the Brown Noddies and Sooty Terns by noting that incident and reflected sound waves double the sound

pressure at ground level (an increase of 6 dB). Since the Brown Noddies nest in brush and since they sit on their eggs instead of standing and shading them, their eggs would not have been exposed to the highest sound levels.

Extensive laboratory studies were conducted after the incident to determine whether sonic booms could affect hatchability (Heinemann and LeBrocq, 1965; Cottereau, 1978; Teer and Truett, 1973; Cogger and Zegarra, 1980). These studies failed to find evidence of structural failure of eggs and calculations made by aeronautics engineers at the time indicated that the sonic booms from low-flying aircraft have insufficient magnitude to damage eggs (letter to Col. J. P. Taylor from Boeing Co., 5 November 1970).

These studies and theoretical calculations were never published in a reviewed journal. While Cottereau (1972) exposed eggs to very intense sonic booms (20 psf), he did not conduct statistical tests to determine whether subtle differences in hatchability or egg development could be detected. None of the authors tested the possibility that high frequency impulses, that is impulses with energy closer to the resonance frequency of a small form like an egg, could cause structural damage. Therefore, Bowles *et al.* (1991) used explosive pest-control devices to expose infertile and fertile chicken eggs to high-intensity impulses with significant energy at high frequencies (500-1,000 Hz). These tests failed to find any evidence of structural failure or cracking.

These experiments demonstrated that eggs are unlikely to crack after exposure to high-intensity impulses, regardless of frequency. They also demonstrated that chick weight and development did not differ significantly after hatching (Cogger and Zegarra, 1980; Keller, 1971). However, these experiments either failed to expose eggs to the most intense sonic booms or failed to conduct statistical tests that demonstrated the validity of the finding that hatchability was unaffected. Additionally, they did not measure the resonance frequencies of the eggs, which would have given a good indication of the potential for damage from sonic booms. Therefore, another series of experiments was planned to determine whether very high-amplitude simulated

sonic booms of long duration could affect the development of eggs and to measure resonance frequencies. This experiment is reported below.

2.0 METHODS

Chicken eggs were used in these experiments for ease of handling and to make the results of the experiments easier to compare with previous studies. These eggs are somewhat larger than Sooty Tern eggs with twice the volume (typical length 51 mm, width 36 mm, volume 35.23 cm^3 *vs*. length 57 mm, width 42 mm, and volume 53.59 cm^3; Whittow, 1985; Romanoff and Romanoff, 1972). Because a larger body is likely to resonate at lower frequencies, chicken eggs would have a somewhat greater tendency to resonate when exposed to sonic booms than Sooty Tern eggs.

2.1 Handling and Exposure of Eggs

Two-hundred and fifty-two fertilized white leghorn chicken eggs were used in these experiments. Test eggs were purchased from two commercial growers in the San Fernando Valley near BBN Systems and Technologies, the site of the Sonic Boom Test Facility (SBTF). They were transported by road from the growers to BBN within two days of laying. To prevent cracking and to reduce vibration during transport, they were placed in 5-gallon buckets filled with goose down. At the test site, they were separated into four different groups. This was accomplished by giving each egg a number at the time it was drawn from a bucket, and then drawing numbers at random to assign eggs to the four groups. Eggs were weighed, measured, and candled with a low-power candling device; flawed and cracked eggs were discarded. The remaining eggs were set within 24 hours of purchase in a G.Q.F. Sportsman self-turning incubator (Model 1202). This was defined as Day 0 of incubation.

On Day 2, eggs were first exposed to simulated sonic booms; thereafter, they were exposed daily until Day 19. At weekly intervals during this period, the eggs were weighed and the diameter of the airspace was measured with calipers. Eggs were also candled twice daily, immediately before and after exposure. The percentage of vascularization and condition of the egg was recorded every day. Room temperatures averaged around 20°C and no egg was outside

the incubator for more than two hours per day. Eggs began to pip the afternoon of Day 18. Once pipped, they were transferred to a G.Q.F. hatcher/brooder (Model 1250).

In the incubator, eggs were separated into groups on four trays. The trays were turned constantly with an automatic turner and were rotated horizontally each day to insure that minor variations in temperature and humidity within the incubator did not bias results. The incubator was checked 3-4 times per day to insure that temperature and humidity were constant. After the embryos penetrated the chorionic membrane (pip), eggs were prepared for hatching by transferring them to the hatcher/brooder.

Dry bulb incubation temperature was held at 99.5°F and wet bulb temperature (humidity) was held at 82°F throughout incubation. After pipping, the eggs were placed on their sides in the hatchette trays with the small end slightly lower than the large end. A second tray of water was placed in the hatcher to increase wet bulb temperature to 89°F to ensure proper humidity during hatching. As chicks hatched and dried off, they were removed from the brooder and placed into pens by group.

The chicks were observed and videotaped for 3-4 days to insure that they were developing normally. Observers looked for chicks that had difficulty orienting on and pecking at food items, lameness, a tendency to walk in circles, or other signs of gross abnormalities in orientation, locomotion or balance. The chicks were also tested with a loud impulse (a pair of metal pipes struck together) to determine whether they had an acoustic startle response. This test would not have been adequate to determine whether chicks had partial hearing loss. They were fed commercial starter mash *ad libitum* during this period.

During the 19-day exposure period, Groups A, B, and D were exposed to ten simulated sonic booms/day. Group C was handled exactly the same way as the exposed groups, but without the simulated booms. The three test groups were exposed to ten booms spaced ten seconds apart. Group A was exposed to 3-psf sonic booms (144 Pa), Group B to 20-psf sonic

booms (957 Pa), and Group D to 30-psf sonic booms (1,436 Pa). Each day all four groups were placed on wooden trays (36 eggs/tray), and then placed in the test compartment of the SBTF (Figure 1). Each egg was placed in a separate compartment on a layer of sand to simulate the substrate on which Sooty Tern eggs were exposed on the Dry Tortugas.

Twenty-four chicken eggs were set aside to determine the vibration frequency of eggs. The eggs were labeled and placed on the bottom shelf of the incubator, and were turned by hand twice daily. They were divided into three groups of eight and each group was tested at weekly intervals (Day 0, Day 7, and Day 14). Test eggs were glued to a mechanical vibration platform for testing and were destroyed immediately after each test.

2.2 Description of Exposures

In its standard configuration, the BBN Sonic Boom Test Facility (SBTF) could not generate the 30-psf test pressures called for by the test plan, nor was the facility designed to safely or efficiently handle large numbers of eggs. To solve these problems, a specially-designed test fixture was constructed to provide the necessary overpressures as well as a convenient method for inserting test specimens. Figure 1 shows a general view of the test fixture, which consisted of a central pressure chamber connected to two opposed SBTF drivers. This arrangement allowed N-waves of up to 30 psf to be generated. The two removable egg trays rested in internal runners that in turn served as sidewall stiffeners for the pressure chamber. A maximum of 72 eggs could be tested at a time with the fixture. The test fixture was housed inside the SBTF, and all tests were done with the SBTF sealed.

The standard SBTF data acquisition system (DAS) was used to collect measurement data during the egg hatchability experiment. As shown schematically in Figure 2, the DAS is based on a DEC VAXstation-II/GPX workstation, with DEC 12-bit D/A and A/D converters used to generate and digitize all test signals. A test facility technician interactively set up, started and monitored each test session for the egg hatchability tests.

Figure 1: Photograph of the setup in the Sonic Boom Test Facility used to expose the test eggs.

All elements of the SBTF data acquisition system were calibrated prior to the testing. During the egg hatchability experiment, ten test parameters were monitored, including test pressure, temperature, relative humidity, and parameters related to SBTF performance.

All signals sent to the SBTF power amplifiers were passed through a 100-Hz, 8th-order Butterworth low-pass filter to protect the loudspeaker modules. All sonic boom waveforms employed during the tests included a 100-ms delay, allowing the A/D system to collect 100 ms of data before the onset of the simulated boom.

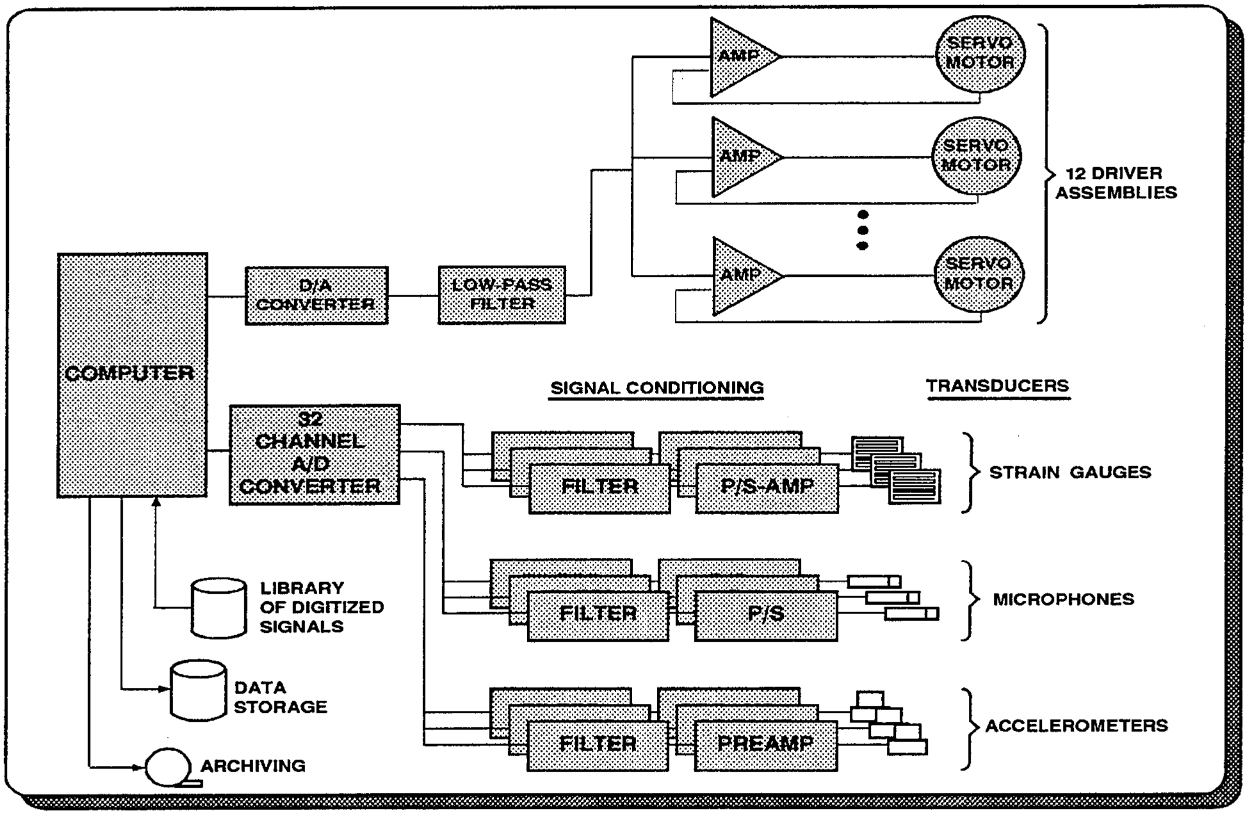


Figure 2: Schematic of the setup used to generate simulated sonic booms in the Sonic Boom Test Facility.

Throughout the experiment, the A/D converter was configured to synchronously sample the data channels at a rate of 1,000 samples/second, collecting a total of 3 seconds per simulated boom. This sample rate was selected to provide adequate temporal definition of the pressure waveform, necessary to estimate pressure maxima and minima. An anti-aliasing cutoff frequency of 250 Hz was used for all data channels. All A/D data were stored to disk for further analysis.

2.2.1 Instrumentation Calibration

Instrumentation calibration was performed by separately calibrating the three major elements of the DAS: transducers, signal conditioning electronics, and the A/D converter. Sound pressure measurements were made using Brüel & Kjær (B&K) condenser microphones, with

B&K preamplifiers and power supplies. All microphones were calibrated using NIST-traceable transfer standards prior to testing. Thermocouples (for temperature measurements) and relative humidity sensors were used directly, relying on manufacturer-supplied calibration information. Because these were treated as non-critical test parameters, no independent calibration of temperature or humidity sensors was performed.

All anti-aliasing filters and signal preamplifiers were checked for correct operation, and to verify that gain, input offset, and noise levels were within acceptable limits. All checks and adjustments were done using precision digital multimeters with current, factory-maintained calibration.

The A/D converter includes a precision voltage reference chip, and is self-calibrating in normal use. An independent check of the A/D converter was made prior to testing by applying a calibrated external voltage source and examining the A/D converter output. This check showed the A/D to be within manufacturer-specified limits. As a final step, end-to-end calibration checks of the microphones were made using NIST-traceable pistonphone calibrators.

2.2.2 Sonic Boom Waveforms

The sonic booms selected for these experiments were intended to simulate (1) exposures that birds might normally experience in rookeries overflown by supersonic aircraft, and (2) worst-case scenarios, where rookeries might be overflown at low altitudes (< 1,000 ft) and at supersonic speeds, within visual range of birds. Tables 1, 2 and 3 show the peak overpressures and sound pressure levels (in dB CSEL) of such sonic booms. These booms would be perceptible to birds within the carpet width of the boom, which is defined by the lateral cutoff distance on either side of the aircraft, measured perpendicularly to the trackline. Beyond this cutoff point, the sound still might be perceptible as a rumble but not as a sonic boom. All of these data presume aircraft flying over the ground at mean sea level (MSL).

Table 1: Estimated altitude of an F-4E aircraft at Mach 1.1 that would produce approximately the sonic boom overpressures tested in these experiments.

Aircraft Altitude (ft above MSL)	Peak Overpressure (psf)	Level (dB CSEL)	Duration (ms)	Carpet Width (2*Lateral Cutoff, in ft)
17,000	3.4	112	139	50,374
1,500	21.5	128	69	21,710
825	30	132	59	14,682

Table 2: Sonic boom overpressure *vs.* lateral distance for an F-4 aircraft at Mach 1.1 and 825 ft altitude MSL (a worst-case scenario, in which aircraft would be visible to nesting birds).

Lateral Distance From Trackline (ft)	Peak Overpressure (psf)	Level (dB CSEL)
0	30	132
1,000	22	129
7,000	2.3	109
7,431 (Lateral Cutoff Distance)	2.1	108

Table 3: Sonic boom overpressure *vs.* lateral distance for an F-4E aircraft at Mach 1.1 and 19,000 ft altitude MSL (at this altitude, the aircraft would be invisible to nesting birds).

Lateral Distance From Trackline (ft)	Peak Overpressure (psf)	Level (dB CSEL)
0	3.0	111
5,000	3.0	111
10,000	2.8	110
20,000	0.8	100
23,417 (Lateral Cutoff Distance)	0.8	99

Part of the calibration was to compute "corrected" sonic boom waveforms for the actual tests. The input waveform to the SBTF amplifiers was modified from the idealized N-wave in order to compensate for the transfer function of the full test system. The objective was to apply a waveform that would, after going through the full electro-mechanical system represented by the driver/test fixture combination, result in the ideal pressure time history. This was achieved by first applying a calibration boom using the idealized N-wave signature as the amplifier input. The ideal N-wave and the resulting test chamber pressure were then processed by first calculating the finite Fourier transforms:

$$X_{ideal}(f) = \frac{1}{T}\int_0^T x_{ideal}(t)\, e^{-i2\pi ft}\, dt$$

$$X_{meas}(f) = \frac{1}{T}\int_0^T x_{meas}(t)\, e^{-i2\pi ft}\, dt$$

where $x_{ideal}(t)$ and $x_{meas}(t)$ are the input (ideal) and pressure (measured) waveforms respectively. From these the frequency response function was computed, inverted, and multiplied by the transform of the (ideal) N-wave, giving a frequency domain representation of the corrected signal:

$$H(f) = \frac{X_{meas}(f)}{X_{ideal}(f)}$$

$$X_{corr}(f) = \frac{X_{ideal}(f)}{H(f)}$$

Next, an inverse-FFT operation was performed to arrive at the desired time series:

$$x_{corr}(t) = \frac{1}{T}\int_0^T X_{corr}(f)\, e^{i2\pi ft}\, df$$

This new waveform, when applied to the amplifiers, resulted in a test chamber pressure that closely approximated the ideal N-wave shape.

2.3 Measurements of the Resonance Frequency of Eggs

The first modal resonance frequency of 23 chicken and 4 quail eggs was measured. The purpose of these tests was to discover whether the resonance frequency of the eggs fell in the range within which simulated sonic booms have significant energy.

Measurements were made by attaching each egg to a shaker table and driving it vertically with a 0.1-g constant-acceleration sine sweep. The relative motion of the egg was monitored using a probe that did not actually contact the egg. The first mode (deformational) of the egg was identified by looking for out-of-phase motion between the top and sides of the shell during the sine sweep. This proved to be a very straightforward method, with distinct, lightly-damped resonances found for each egg.

3.0 RESULTS

3.1 Exposures

Table 4 summarizes the test level measurements made during the experiment. Figures 3 through 5 show typical waveforms and the frequency distribution of the sonic boom levels for each test group. These levels were normally distributed and within 1 Pa of the desired target level. The term 'Target' refers to the desired level for the simulated sonic booms.

Table 4: Levels of simulated sonic booms produced in the Sonic Boom Test Facility.

Group	Target Level (psf)	Target Level (Pa)	Actual Level (mean in Pa)	Standard Deviation (Pa)
A	3	144	143.5	2.2
B	20	957	958.1	5.7
D	30	1,436	1,437.7	3.8

The spectral content of a typical sonic boom at each level is shown in Figures 6 through 8. Virtually all the energy in the simulated booms was below 100 Hz, with peak frequencies at approximately 10 Hz.

3.2 Success of Exposed Eggs

Table 5 summarizes the number of eggs set in each group, the number identified as fertile by candling, the number pipped, the number hatched, and the number surviving from each hatch. It also gives summary statistics on the weights and measurements of eggs in each group and chick weights.

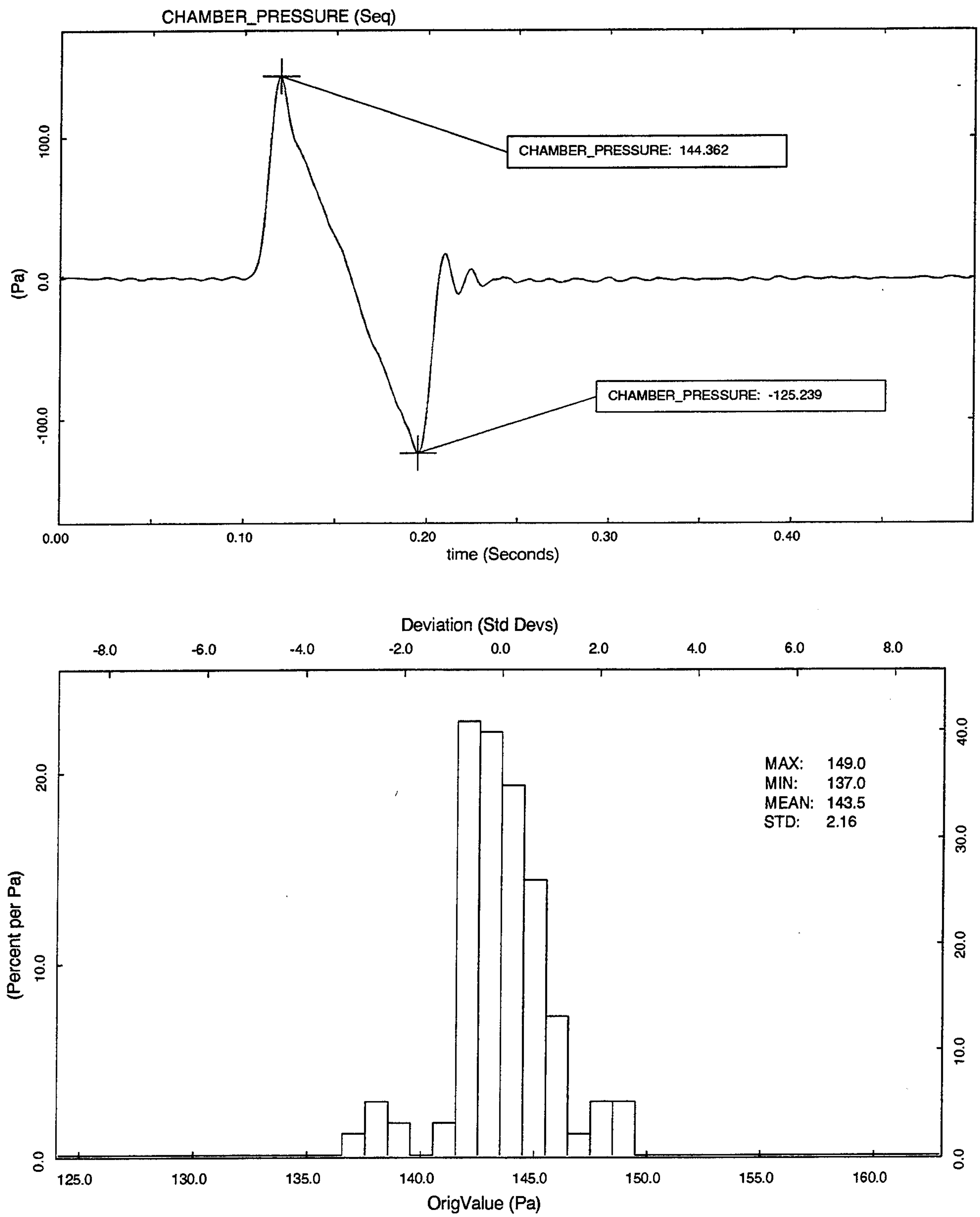
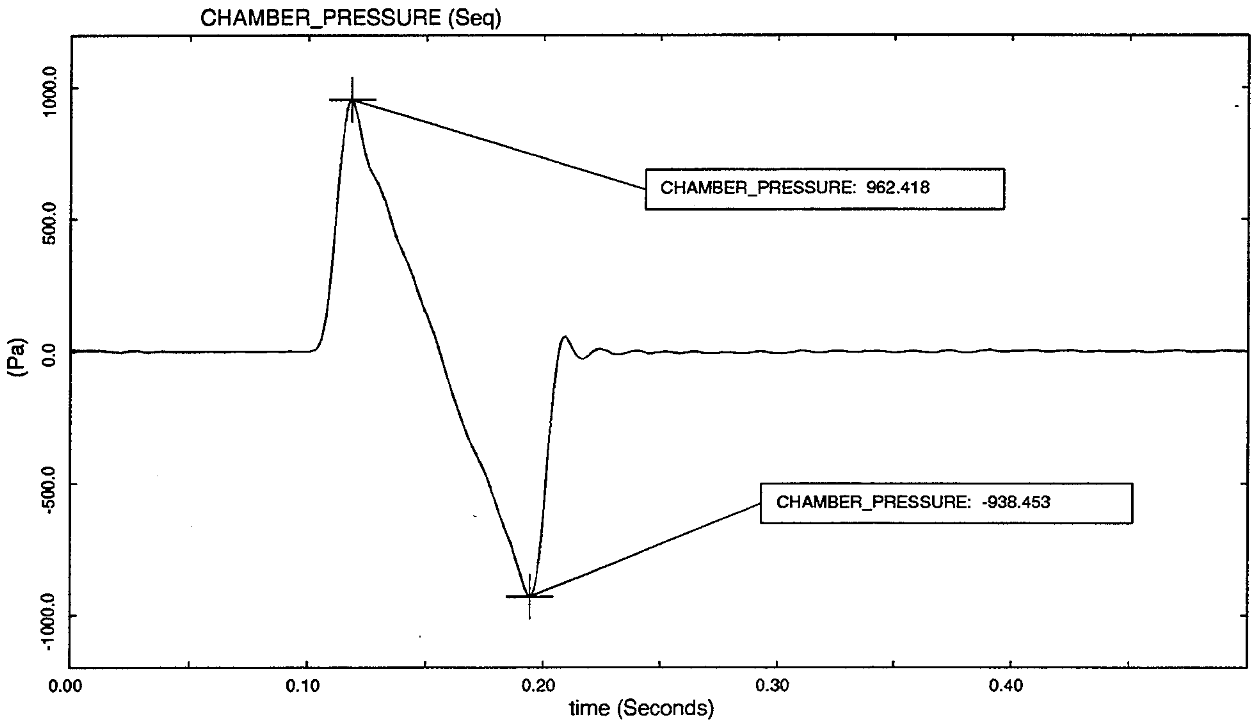


Figure 3: Waveform of a typical 3-psf boom and frequency distribution of the booms delivered to Group A.



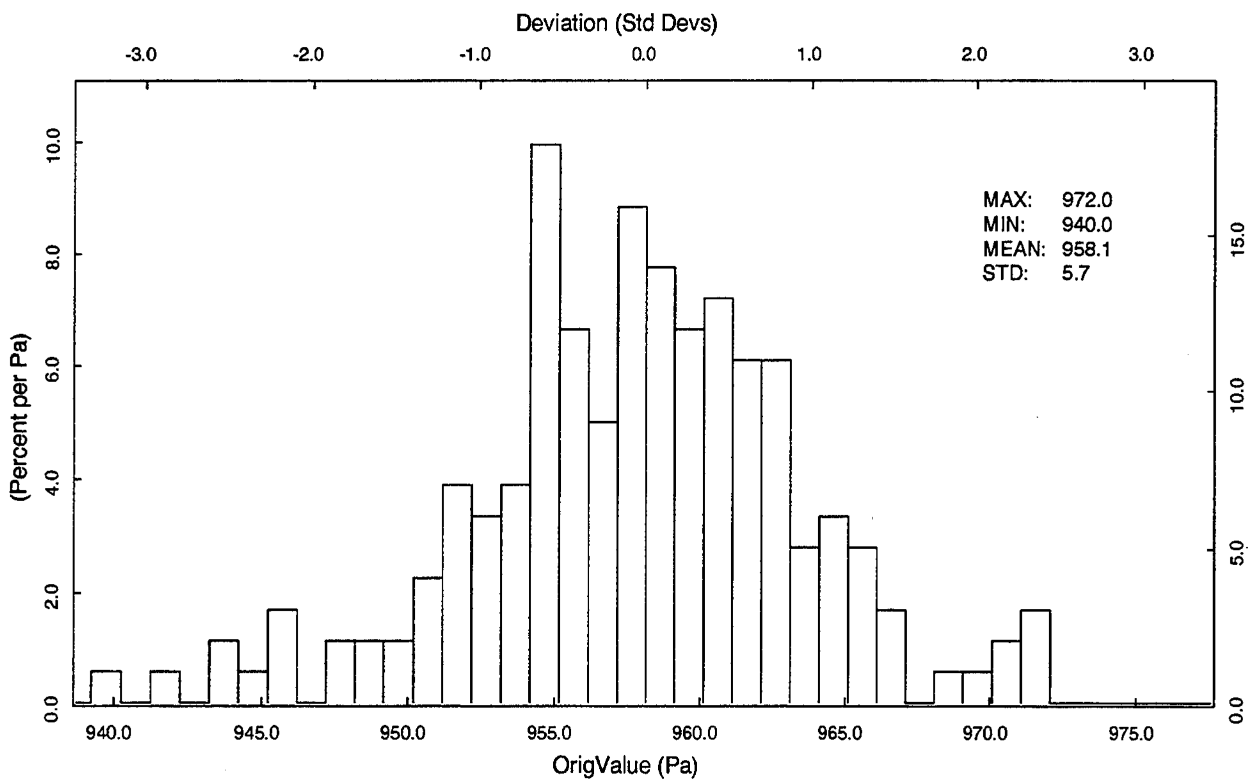


Figure 4: Waveform of a typical 20-psf boom and frequency distribution of the booms delivered to Group B.

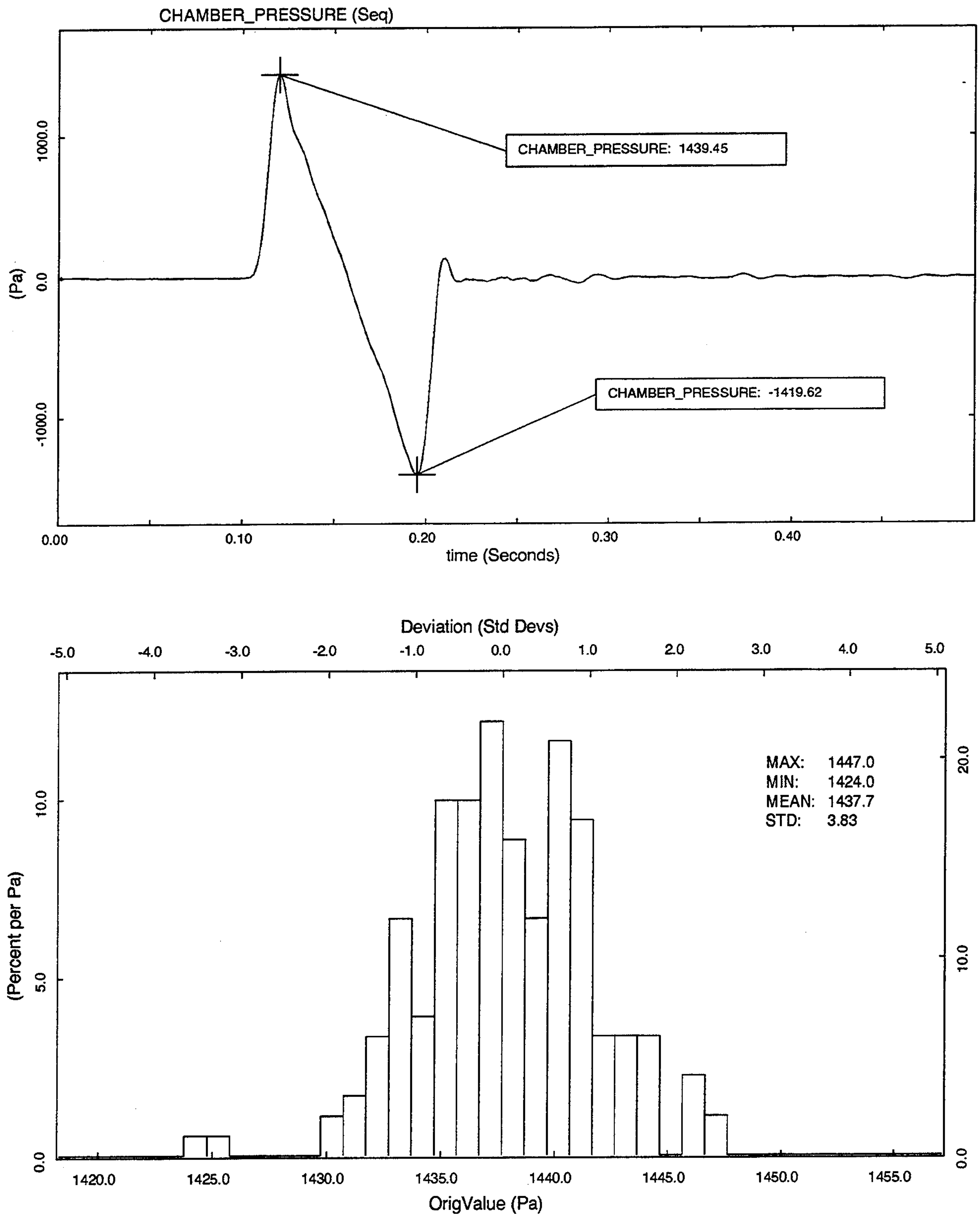


Figure 5: Waveform of a typical 30-psf boom and frequency distribution of the booms delivered to Group D.

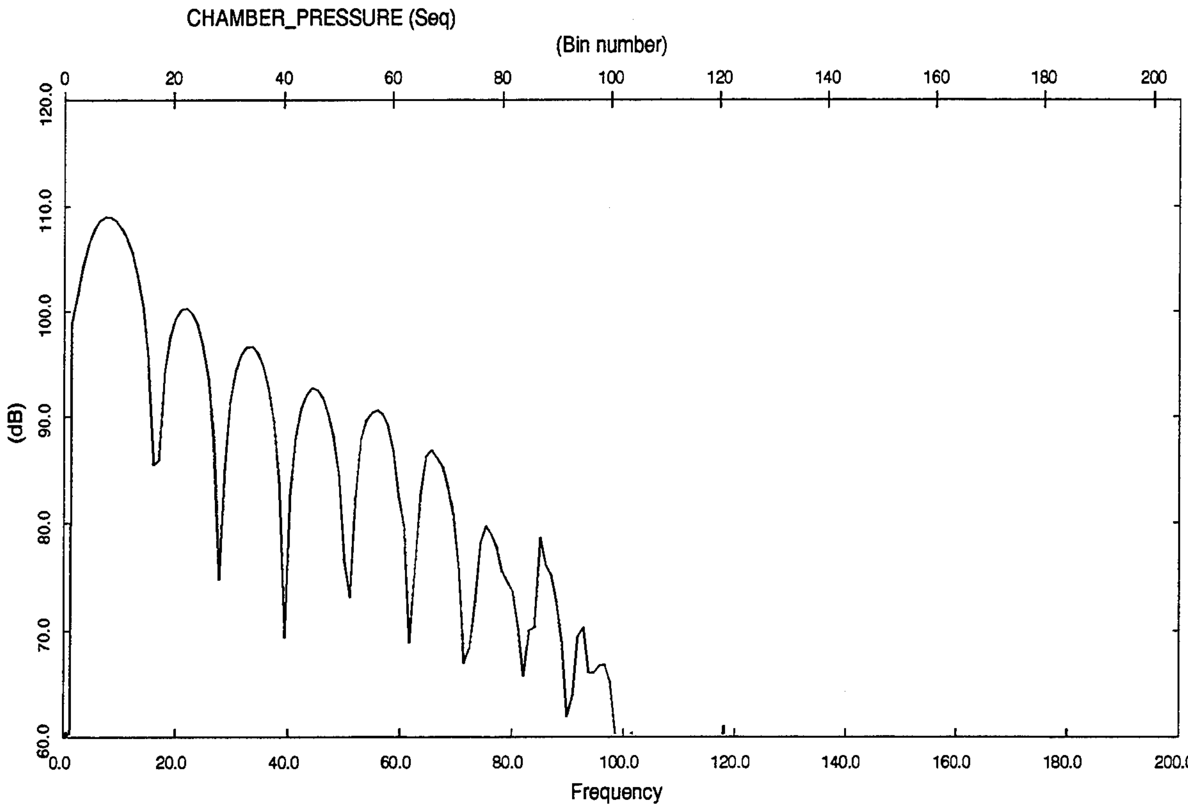


Figure 6: Power spectrum for a typical 3-psf boom.

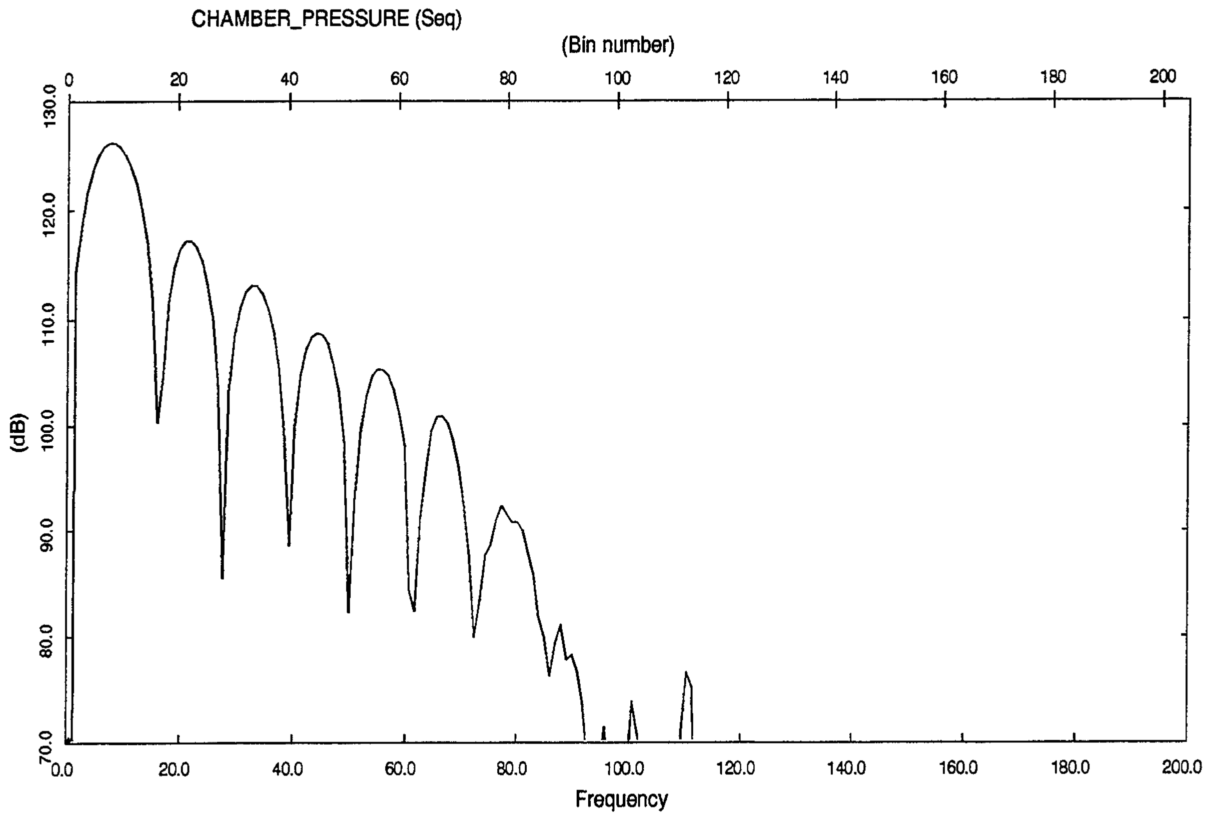


Figure 7: Power spectrum for a typical 20-psf boom.

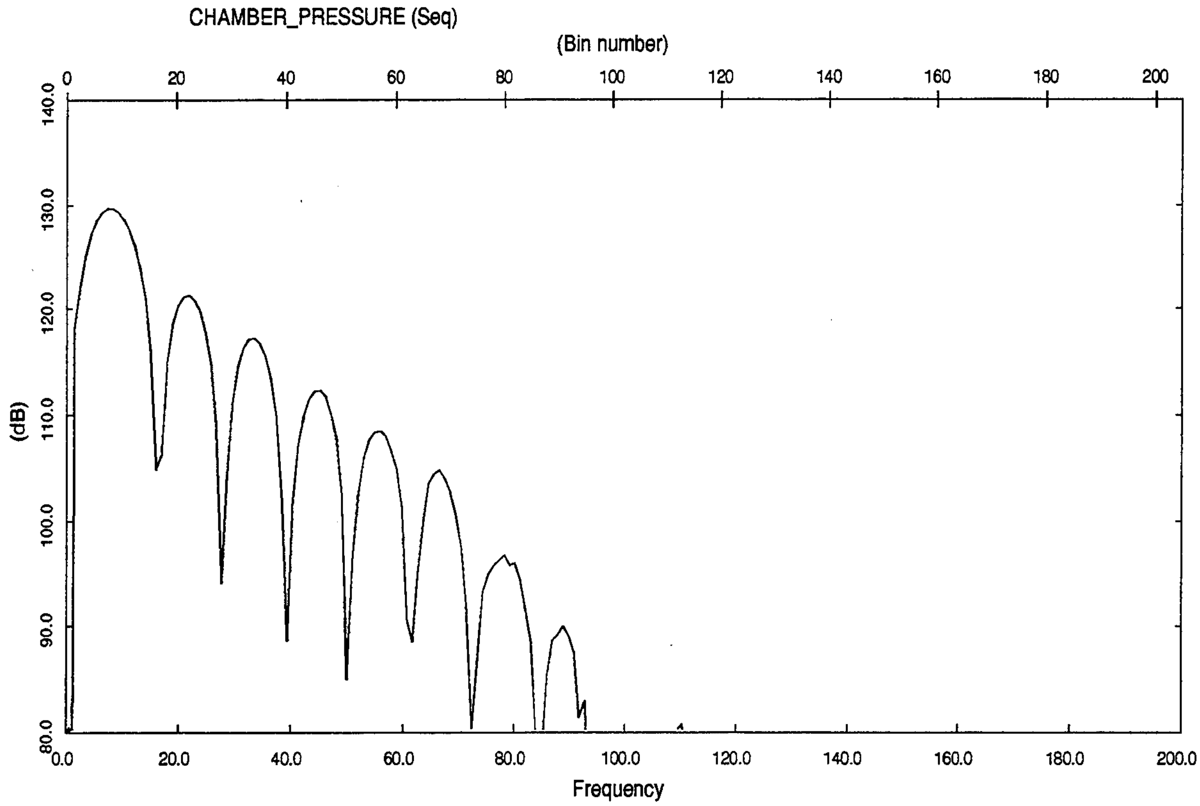


Figure 8: Power spectrum for a typical 30-psf boom.

Table 5: Summary of sample size, success, and morphometric characteristics of eggs and chicks in all four test groups.

Group	A	B	C	D
Total eggs set	63	63	62	58
Total viable (% of eggs set)	60 (95%)	61 (97%)	55 (89%)	57 (98%)
Total pipped (% of viable eggs)	42 (70%)	46 (75%)	45 (82%)	49 (86%)
Total hatched (% of viable eggs)	38 (63%)	45 (74%)	42 (76%)	46 (81%)
Total alive @ 48 hrs post-hatch	38 (63%)	45 (74%)	41 (75%)	45 (79%)
Mean start weight (g)	56.47 (se=0.52)	57.88 (se=0.52)	57.21 (se=0.47)	57.80 (se=0.44)
Mean weight (g) on Day 6	54.34 (se=0.55)	55.62 (se=0.52)	54.80 (se=0.46)	55.50 (se=0.44)
Mean weight (g) on Day 13	51.26 (se=0.59)	52.72 (se=0.50)	51.71 (se=0.54)	52.72 (se=0.42)
Mean length (mm)	56.84 (se=0.35)	57.40 (se=0.52)	57.19 (se=0.24)	57.12 (se=0.65)
Mean width (mm)	43.04 (se=0.35)	43.14 (se=0.27)	42.80 (se=0.12)	43.13 (se=0.26)
Mean chick weight (g) at hatch	39.80 (se=0.64)	38.21 (se=0.39)	38.29 (se=0.50)	38.99 (se=0.45)

3.2.1 Weights and Dimensions

Group A differed slightly from Groups B, C and D in initial weight (56.47 *vs*. 57.21-57.88 gm; ANOVA, $F = 4.9919$, $df = 3,697$, $p < 0.05$; Newman-Keuls *post hoc* test, $p < 0.05$), but none of the groups differed significantly from the control group. These differences persisted

throughout incubation (Figure 9). However, egg lengths and widths did not differ significantly among the three groups (ANOVA on length F = 0.2974, p = 0.8272; width F = 0.3576, df = 3,239, p = 0.7837).

In the control group, weight loss was described by the relation:

$$\text{weight day } X = 57.62 - 0.5111 * X \quad (se = 3.6974)$$

The relation was significant, explaining over 25% of the variance in egg weight (linear regression; $F = 60.452$; df = 1,171; $p < 0.0017$; $R^2 = 0.2569$). Egg lengths and widths did not differ significantly among the three groups (ANOVA on length F = 0.2974, p = 0.8272; width F = 0.3576, df = 3,239, p = 0.7837).

3.2.2 Fertility, Pipping Rate, and Hatchability

Of the eggs set, 89-98% were viable as measured by the presence of vasculature (Table 5). This rate is typical of studies of this type (Appendix A) and within the normal range for domestic White Leghorn chickens. Viability did not differ among the groups (Chi-square Heterogeneity Test, $\chi^2 = 1.2129$, $p > 0.05$). Of the 90 eggs from Red Wing Hatchery, five were infertile or died early in development (5.5%). Of the 156 eggs from CEBE Farms, eight were infertile or died early in development (5.1%).

Eggs died throughout development, but the exact date of death was often difficult to determine until the vasculature appeared obviously deteriorated during candling. Figure 9 shows the number remaining alive against date since the start of the experiment. Losses during the first week were difficult to detect, so most eggs lost during the first week were identified on Days 10-14. This explains the abrupt drop in losses during that period in Figure 10. Most of the rest of the losses were hatch-related (Days 24-28). None of the eggs in any of the groups developed cracks after exposure to the simulated sonic booms.

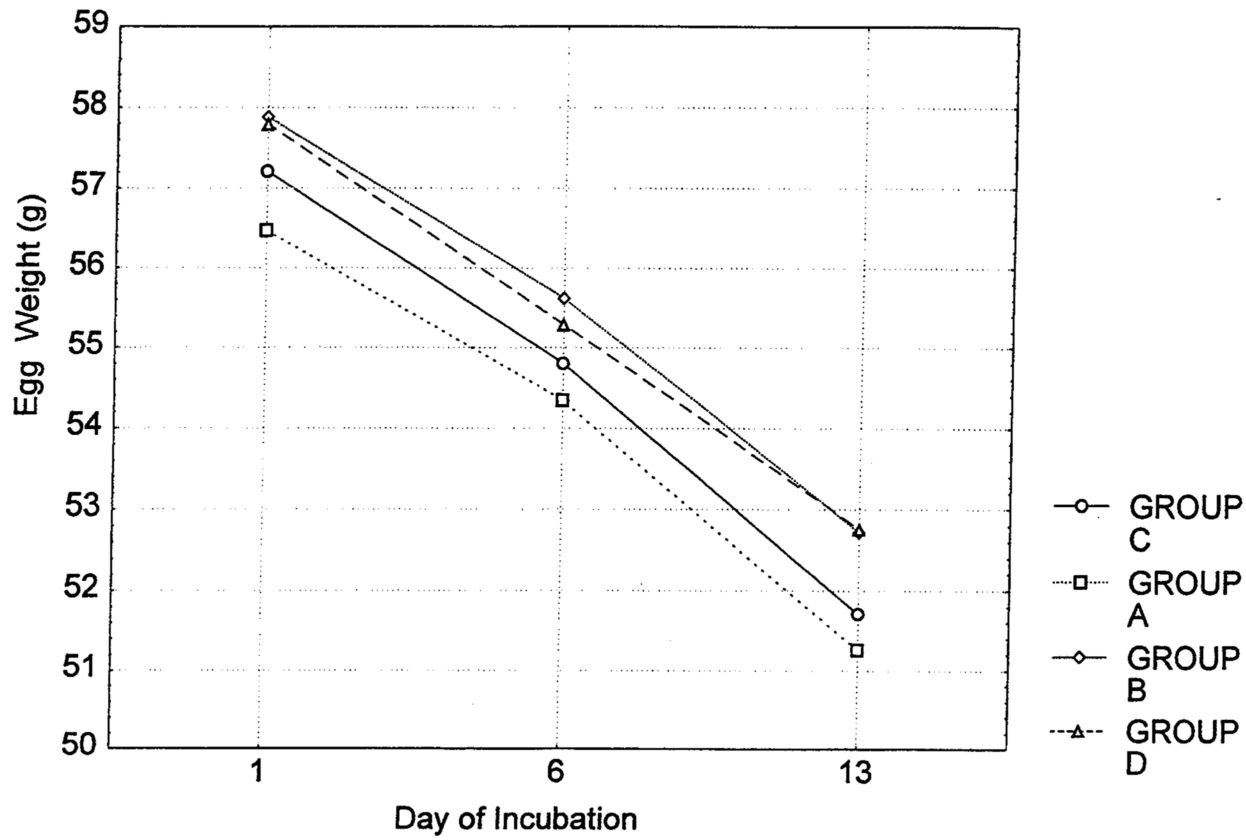


Figure 9: Correlation between egg weight and day of incubation.

Pipping and hatching success of all the groups was comparable to that observed in other studies in which eggs were handled daily (Appendix A) and were within the normal range for commercial hatchery operations. Rates of eggs surviving differed significantly among groups, with groups A and C differing from groups B and D. Survival rate was analyzed using a linear trend comparison (Mantel-Cox criterion; $\chi^2 = 5.67$; df = 1,245; p = 0.0173). Groups B and D had somewhat higher survivorships, even though they received the highest exposures (20 and 30 psf). These differences corresponded to differences in egg weight throughout incubation (Figure 9).

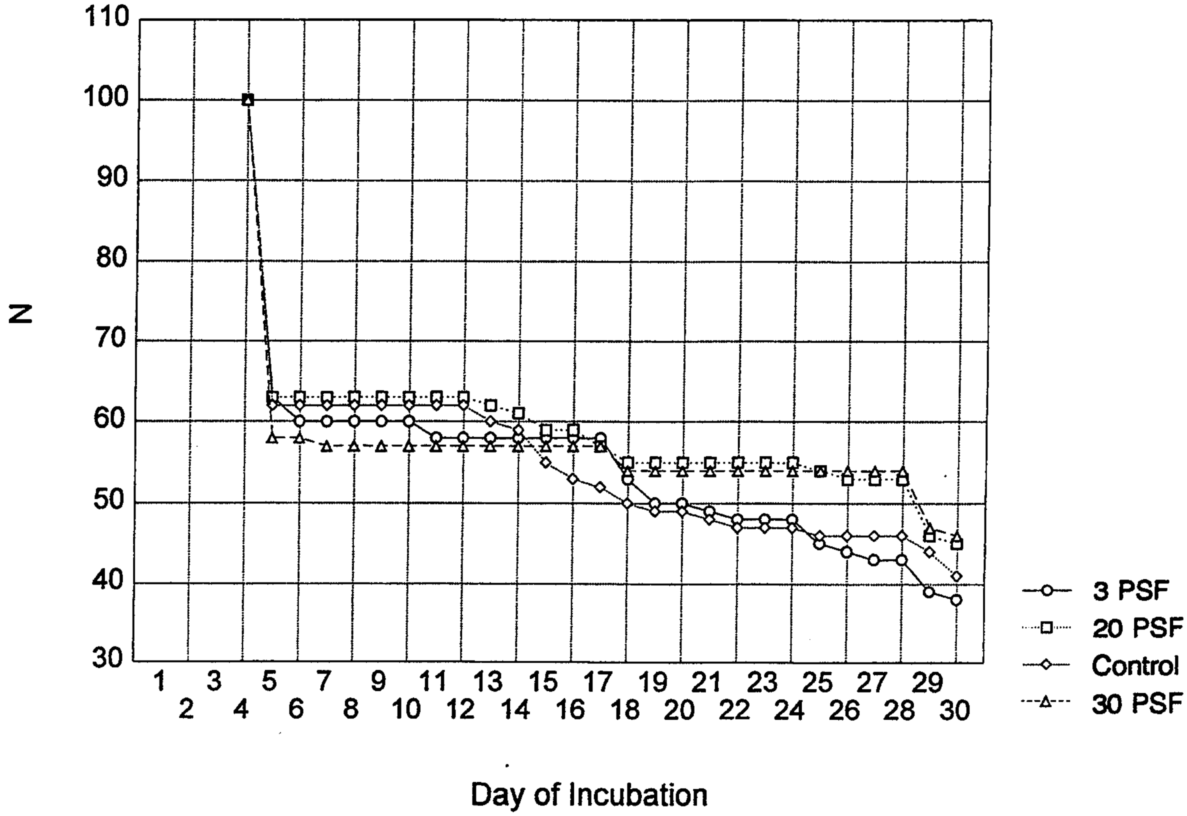


Figure 10: Number of viable eggs in Groups A-D each day of incubation.

This higher survival rate is not without precedent. Higher hatchabilities have been observed in one other study of sonic boom effects on incubating eggs (Teer and Truett, 1973). Figure 11 shows the change in hatchabilities relative to controls gleaned from all the studies on sonic boom effects (Stadelman and Kosin, 1957; Teer and Truett, 1973; Cogger and Zegarra, 1980; Heinemann and LeBrocq, 1978; Keller, 1971). Although the change in hatchabilities in any given series of trials was rarely significantly greater than the hatchability of the corresponding control group, most trials found a slight increase in hatchability. Out of 28 trials in the literature, 50% should have been slightly greater and 50% should have been slightly less by chance. The difference between this expectation and the actual difference (21 trials greater than controls) was significant (Fisher Exact Test, one-tailed, χ^2 = 4.20, df = 1, p = 0.0377).

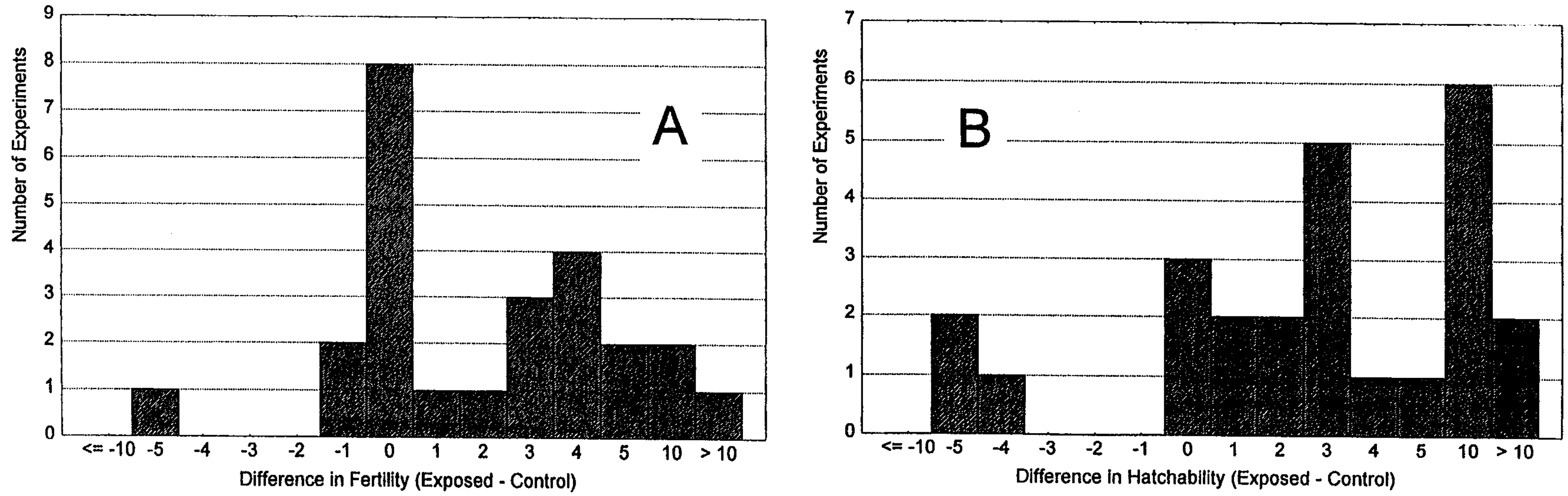


Figure 11: Difference in fertility (A) and hatchability (B) between control and exposed groups in previous studies (Heinemann and LeBrocq, 1965; Teer and Truett, 1973; Cogger and Zegarra, 1980; Keller, 1993).

As in most other individual studies, the hatch and pip rates of eggs in this study did not differ significantly from the control group. In this case, the success of the control group lay between the success rates of the least and most exposed groups. The lowest successes were found in Group A (37% of viable eggs lost), which received 3-psf booms, and the greatest successes in Group D (21% of eggs lost), which received 30-psf booms. The most parsimonious explanation for differences in hatchabilities among the groups is the difference in egg weights.

The date of peak pipping was apparently delayed by one day in Groups C and D (Table 6, Figure 12), but the date of peak hatching was comparable among all groups (Table 7, Figure 13). Neither of these differences could have affected egg survivorship. Probit analysis (Caughley, 1977; Caughley and Caughley, 1974) was attempted as a method for comparing peak pip and hatch dates among the different groups, but the hatch and pip dates were not normally distributed and the median pip and hatch dates identified by the test were outside the actual range observed.

There were no detectable differences in rate of development among the four groups as measured by the percentage of the chorion that was vascularized (Figure 14).

Table 6: Summary of number of eggs pipped by group and date.

Date	Day	A	B	C	D
4/26	19	10	2	7	10
4/27	20	12	13	14	7
4/28	21	14	24	6	10
4/29	22	6	7	18	22
4/30	23	0	0	0	0
5/1	24	0	0	0	0
Total		42	46	45	49

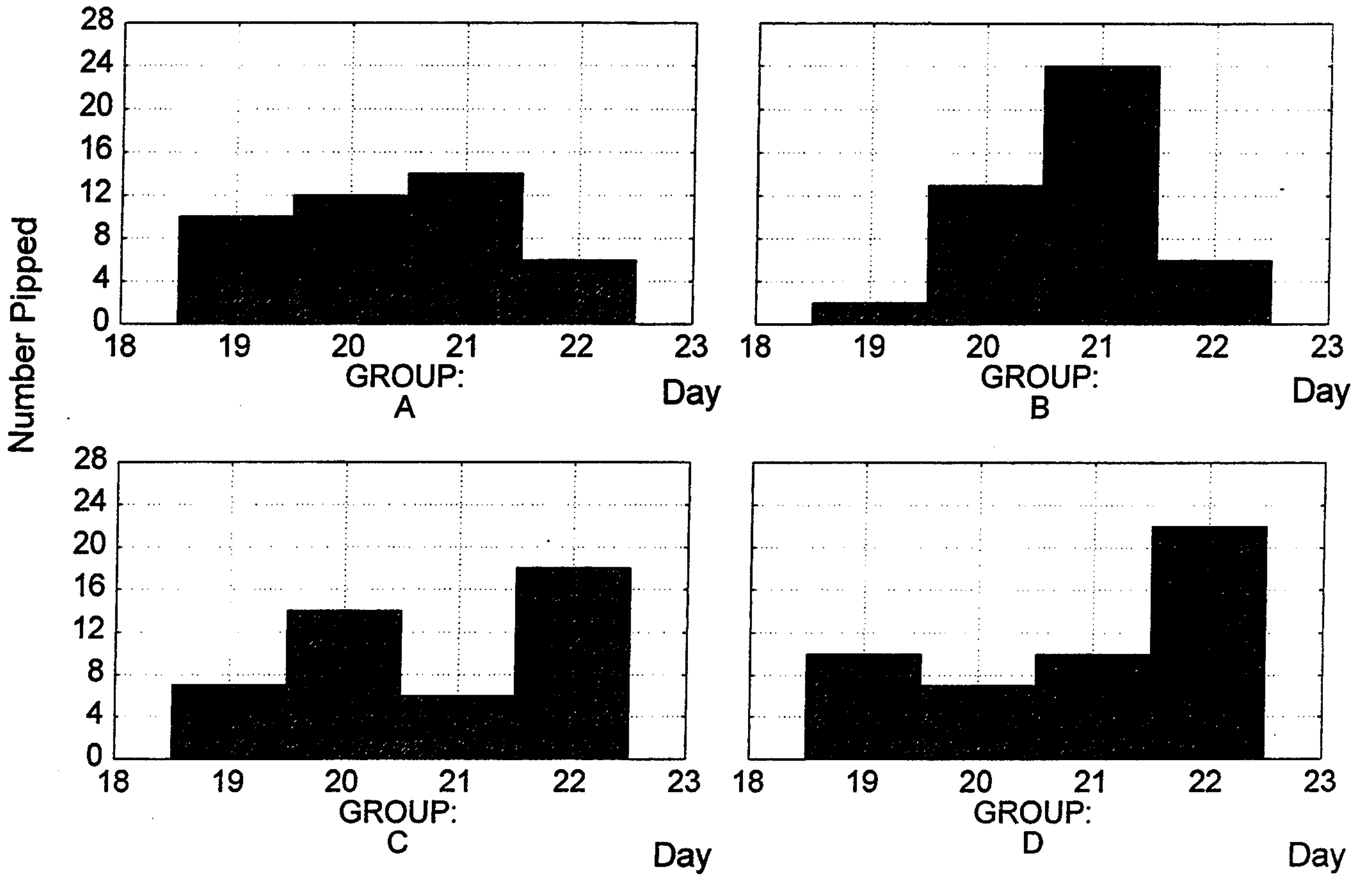


Figure 12: Distribution of pipping dates for eggs in all four groups.

Table 7: Summary of number of eggs hatched by group and date.

Date	Day	A	B	C	D
4/27	20	4	1	0	0
4/28	21	13	11	18	15
4/29	22	4	11	5	8
4/30	23	16	22	12	22
5/1	24	1	0	7	1
Total		38	45	42	46

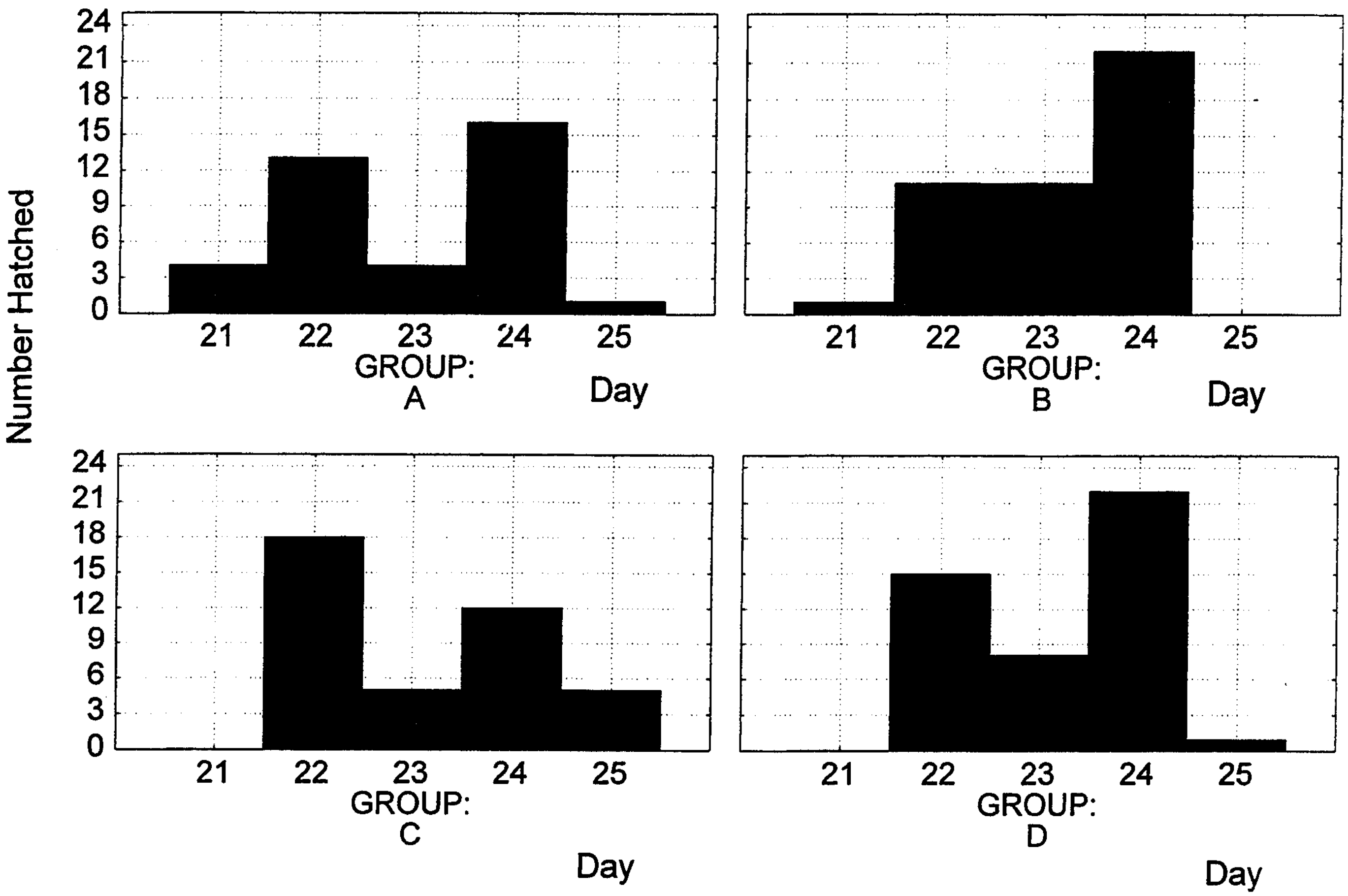


Figure 13: Distribution of hatch dates for eggs in all four groups.

All the chicks that lived had normal locomotion and responded to impulse noise with a startle. There was no evidence of difficulty in pecking or orientation suggestive of vestibular damage. Chick weights did not differ significantly among the groups (1-way ANCOVA on weight and resonance frequency, holding day as a covariate; $F = 0.7568$; $df = 3,175$; $p = 0.5198$).

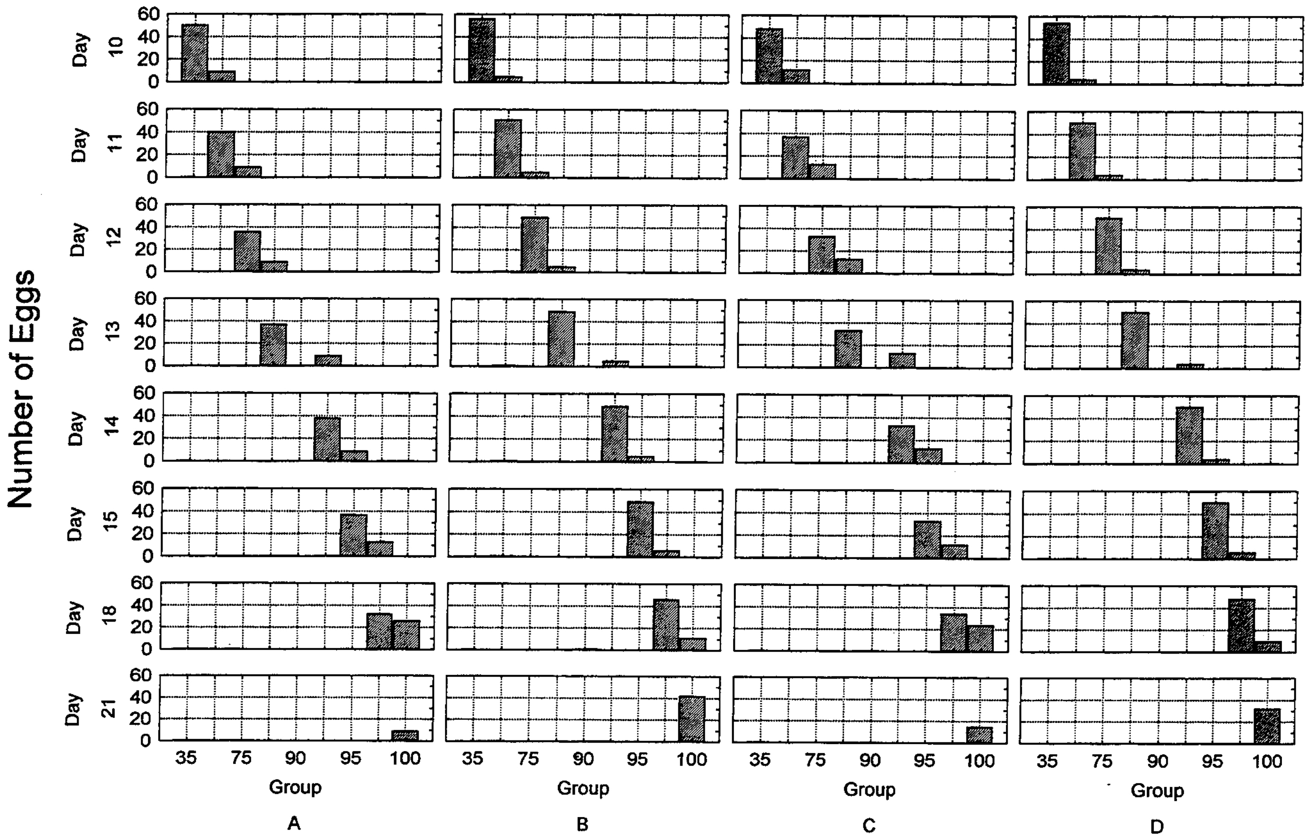


Figure 14: Percentage of vascularization from Day 10 to Day 21 of development (the ordinate indicates the percentage of vascularization, broken down by group).

3.3 Resonance Frequencies of Eggs

Table 8 summarizes the results of the measurements of egg resonance. The first resonance mode of the chicken eggs ranged between 468 and 1,036 Hz. Resonances of the quail eggs were higher, not unexpectedly, ranging between 1,274 and 1,475 Hz. In the fertile chicken eggs, resonance frequency declined slightly during development, but day, weight, and airspace size did not correlate significantly with resonance frequency (multiple regression $F = 2.2152$; $df = 3.19$; $p = 0.1196$). The resonance frequencies of the eggs were all 6-7 octaves above the

peak energy in the simulated sonic booms, which was at approximately 10 Hz (Figures 6 through 8).

Table 8: Summary of results of resonance measurements in chicken and quail eggs.

Egg ID	Egg Type	Resonance Frequency (Hz)	Egg ID	Egg Type	Resonance Frequency (Hz)
V1	Chicken	666	V15	Chicken	700
V2	Chicken	658	V16	Chicken	990
V3	Chicken	695	V17	Chicken	593
V4	Chicken	1,036	V18	Chicken	700
V5	Chicken	677	V19	Chicken	495
V6	Chicken	833	V20	Chicken	468
V7	Chicken	781	V21	Chicken	405
V8	Chicken	540	V22	Chicken	753
V9	Chicken	811	V23	Chicken	727
V10	Chicken	894	V24	Chicken	562
V11	Chicken	935	QV4	Quail	1,370
V12	Chicken	687	QV7	Quail	1,475
V13	Chicken	740	QV8	Quail	1,274
V14	Chicken	-	QV9	Quail	1,280

4.0 DISCUSSION

These experiments did not provide any evidence of physical damage to egg shells or embryos (such as cracking or excessive embryonic death) as a result of exposure to intense simulated sonic booms. In fact, the results are entirely consistent with the results of previous studies, which found no difference or a slight advantage in hatchability of eggs, weights of eggs, and weights of chicks (Heinemann and LeBrocq, 1965; Teer and Truett, 1973; Cogger and Zegarra, 1980; Keller, 1971).

Hatchabilities were significantly greater after exposure to sonic booms in one previous study (Appendix A). In all the studies combined, significantly more trials found higher hatchabilities than lower (Figure 11; Section 3.2.2). Fertilities did not differ significantly in any study nor in the data from all studies combined. Based on the loss rates measured daily in this study, the difference in hatchability among groups is most likely to have arisen as a result of differences in the mean initial weight of each group, because laying weight is known to correlate with hatching success in many species (Rickleffs, 1980; Grant, 1991).

The differences in hatchabilities were not explained by handling, as all groups were handled similarly. Groups A/C and B/D were not held in the same tray within the incubator, or in the same position within their respective trays, and all the trays were rotated among the four slots in the incubator (top to bottom).

Studies of the resistance of eggs to cracking and acceleration suggest that no physical effects of sonic booms on eggs and embryos can be expected because eggs are highly resistant to uniform pressure fields and because tissues require constant or large accelerations (Besch *et al.*, 1965; Sluka *et al.*, 1965) to produce damage. The tests reported here and the previous studies of effects on hatchability certainly support this contention. Effects on the hearing of embryos are also unlikely because there is a large impedance mismatch between air and the watery medium in which the chick lives until it hatches (the intensity of sound crossing the air-

water interface is 1/60th of that in air). However, the possibility of temporary or partial hearing loss was not examined in this study.

If the Sooty Tern Incident cannot be explained by physical effects on eggs or embryos, it is possible that repeated exposure of adults could have resulted in some effect on broodiness. Broodiness can be interrupted by exposure to impulsive and transient noise (*e.g.*, Jeannotout and Adams, 1961; Stadelman and Kosin, 1957), although this effect has not been noted in studies of wild birds exposed to sonic booms or other intense impulsive noise (Burger, 1981; Schreiber and Schreiber, 1980; Teer and Truett, 1973), or in captive studies using sonic booms as a stimulus (Cogger and Zegarra, 1980). It is also possible theoretically that adults were driven from their nests for long enough to cause eggs to die from exposure by repeated overflights, although, once again, this effect has not been observed in previous studies.

These two potential explanations for the Sooty Tern Incident merit further investigation because they are plausible, but they are by no means the most likely explanations for the mass hatching failure on the Dry Tortugas. Austin *et al.* (1970b) report that the Sooty Terns on the Dry Tortugas had been exposed fairly often to sonic booms previous to the reported incident and these booms had never resulted in departures from the nest for more than a few minutes (these departures are typically for 2-10 minutes; times were not given in the Austin *et al.* report). These observations are consistent with other studies of avian responses to sonic booms (Burger, 1981; Bowles and Stewart, 1982; Schreiber and Schreiber, 1980). Once a clutch is full and the adults are well into incubation, as was the case on the Dry Tortugas, there is no direct evidence, clinical or experimental, that sonic booms can cause abandonment.

In cases where birds are driven from the nest by a brief, noisy disturbance, accidents and predation by gulls or other predators on a colony can occur. The losses due to these causes usually amount to a few percent of the total annual production (*e.g.*, Burger, 1981). Intense exposures that can be perceived as attacks (*e.g.*, approach by a very low-flying aircraft) or prolonged exposure to disturbances are required to drive birds from their nests for long enough

to cause mass hatching failures. The factors that have caused mass failures in the past are (1) low-altitude hazing from aircraft (*e.g.*, Bunnell *et al.*, 1981), (2) parasite infestations (Feare, 1976), (3) attacks by mammalian predators (Emlen *et al.*, 1966), and (4) unusual climatic conditions (Schreiber and Schreiber, 1984). Austin *et al.* (1970b) rejected most of these explanations as causes for the Sooty Tern Incident based on their observations a month after the fact; but, because no one was watching the birds during the period when the failures occurred, it is possible that the evidence for a natural cause of the hatching failure was later obliterated. There is no evidence, based on the observations of personnel at nearby Fort Jefferson, that the supersonic aircraft flew at low altitudes over the Dry Tortugas colony.

REFERENCES

Anonymous (1969). "The death of birds." Environment, 11(6): S-1.

Austin, O. L., Jr., W. B. Robertson, Jr., & G. E. Woolfenden (1970a). "Mass hatching failure in Dry Tortugas Sooty Terns." Proc. Int. Ornithological Cong., 15:627.

Austin, O. L., Jr., W. B. Robertson, Jr., & G. E. Woolfenden (1970b). Unpub. Ms. "Mass hatching failure in Dry Tortugas Sooty Terns." Manuscript archived in the Van Tyne Ornithological Library.

Bell, W. B. (1972). "Animal response to sonic booms." J. Acoust. Soc. Am., 51(2):758-765.

Bender, A. (1977). "Noise impact on wildlife: An environmental impact assessment." Proceedings of the 9th Conference on Space Simulation. Report by National Aeronautics and Space Administration, Technical Report No. NASA P-20007.

Besch, E. L., A. H. Smith, & M. W. Walker (1965). "Morphological changes in avian eggs subjected to accelerative force." J. Applied Physiology, 20(6):1241-1248.

Bowles, A. E., & B. S. Stewart (1980). "Disturbances to the pinnipeds and birds of San Miguel Island, 1979-1980." Pp. 99-137 IN Jehl, J. R., Jr., & C. F. Cooper (Eds.) Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands: Research Reports. Report by SDSU Center for Marine Studies for the U.S. Air Force.

Bowles, A. E., F. T. Awbrey, & J. R. Jehl (1991). "The effects of high-amplitude impulsive noise on hatching success: A reanalysis of the Sooty Tern Incident." Report prepared by Hubbs-Sea World Research Institute for the Noise and Sonic Boom Impact Technology Program, Brooks Air Force Base, Report HSD-TP-91-0006.

Bunnell, S. L., D. Dunbar, L. Koza, & G. Ryder (1981). "Effects of Disturbance on the Productivity and Numbers of White Pelicans in British Columbia—Observations and Models." Colonial Waterbirds, 4:2-11.

Burger, J. (1981). "Behavioral responses of Herring Gulls (*Larus argentatus*) to aircraft noise." Environmental Pollution, (Series A) 24:177-184.

Caughley, G. (1977). Analysis of vertebrate populations. John Wiley and Sons: London. 234 pp.

Caughley, G., & J. Caughley (1974). "Estimating median date of birth." J. of Wildlife Management, 38:552-556.

Cogger, E. A., & E. G. Zegarra (1980). "Sonic booms and reproductive performance of marine birds: Studies on domestic fowl as analogues." Pp. 163-194 IN Jehl, J. R., Jr., & C. F. Cooper (Eds.) Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands: Research Reports. Report by SDSU Center for Marine Studies for the U.S. Air Force.

Cottereau, P. (1978). "Effect of sonic boom from aircraft on wildlife and animal husbandry." Pp. 63-79 IN Fletcher, J. L., & R.-G. Busnel (Eds.) Effects of noise on wildlife. Academic Press: New York.

Dufour, P. (1980). "Effects of noise on wildlife and other animals." Review of research since 1971. Report prepared by the U.S. Environmental Protection Agency, Office of Noise Abatement and Control, July 1980. National Technical Information Service (NTIS) PB82-139973.

Emlen, J. T., D. E. Miller, R. M. Evans, & D. H. Thompson (1966). "Predator-induced parental neglect in a Ring-billed Gull colony." Auk, 83:677-679.

Ellis, D. H. (1981). "Responses of raptorial birds to low level military jets and sonic booms." Results of the 1980-1981 joint U.S. Air Force/U.S. Fish and Wildlife Service study. Report prepared by the Institute for Raptor Studies for the U.S. Air Force. NTIS AD-A108-887.

Feare, C. J. (1976). "Desertion and abnormal development in a colony of Sooty Terns, *Sterna fuscata*, infested by virus-infected ticks." Ibis, 118:112-115.

Fletcher, J. L., & M. J. Harvey (1971). "Effects of noise on wildlife and other animals." Report by Memphis State University for U.S. Environmental Protection Agency. Contract 68-04-0024. NTID 300.5.

Graham, F., Jr. (1979). "Ear pollution!" Audubon, 71:34-39.

Grant, M. C. (1991). "Relationships between egg size, chick size at hatching, and chick survival in the Whimbrel *Numenius phaeopus*." Ibis, 133:127-133.

Haynes, A. M. (1987). "Human exploitation of seabirds in Jamaica." Biological Conservation, 41:99-124.

Hecock, R., & K. Rhoads (1979). "Noise, aircraft, wildlife, and people: A bibliographic review." Final Report by the Cooperative Wildlife Research Center, Oklahoma State University, prepared for the U.S. Fish and Wildlife Service, April 1979.

Heinemann, J. M., & E. F. LeBrocq (1965). "Effects of sonic booms on the hatchability of chicken eggs." Report by Regional Environmental Health Laboratory, USAF. HL(K) 65-2.

Hinshaw, W., T. Ladson, E. E. McNeil, & J. Taylor (1970). "An annotated bibliography on animal response to sonic booms and other loud sounds." Report for the Federal Aviation Administration. NTIS No. PB 199 034.

Hurtubise, F. G., D. H. McKay, & F. Macenko (1978). "Aircraft pollution: Noise and other types." Proceedings of the 15th Anglo-American Aeronautical Conference, Report Number EPS 3-EC-78-13. Royal Aeronautical Society, London.

Jeannotout, D. W., & J. L. Adams (1961). Progesterone *versus* treatment by high intensity sound as methods of controlling broodiness in broad breasted bronze turkeys. Poultry Science, 40:512-521.

Keller, M. (1971). "The effects of sonic booms on certain animals." [Les effects du bang supersonique sur certains animaux.] Translation by Foreign Aerospace Science and Technology Center, Wright-Patterson Air Force Base, Ohio, 2 June 1993. Report FASTC-ID(RS)T-0860-92, Microfiche 93C000370L. 91 pp.

Kull, R. C., & A. D. Fisher (1986). "Supersonic and subsonic aircraft noise effects on animals: A literature review." U.S. Air Force Systems Command, Wright-Patterson Air Force Base, OH. Report AAMRL-TR-87-032.

Manuwal, D. A. (1978). "Effects of man on marine birds." Pp. 140-160 IN C. M. Kirkpatrick (Ed.) Wildlife and People. Proceedings of the 1978 John S. Wright Forestry Conference, Purdue University, 23-24 February, 1978.

Manci, K. M., D. N. Gladwin, R. Villella, & M. G. Cavendish (1988). "Effects of aircraft noise and sonic booms on domestic animals and wildlife: A literature synthesis." Technical Report NERC 88/29 and AFESC TR 88-14. Report by USFWS NERC for USAF NSBIT Program, Wright-Patterson Air Force Base.

Rickleffs, R. E. (1980). "Egg dimensions and neonatal mass of shorebirds." Condor, 86: 7-11.

Romanoff, A. L., & A. J. Romanoff (1972). The Avian Egg. John Wiley and Sons: New York.

Schreiber, E. A., & R. W. Schreiber (1980). "Effects of impulse noise on seabirds of the Channel Islands." Pp. 138-162 IN Jehl, J. R., Jr., & C. F. Cooper (Eds.) Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands: Research Reports. Report by SDSU Center for Marine Studies for the U.S. Air Force.

Schreiber, R. W., & E. A. Schreiber (1984). "Central Pacific seabirds and the El Niño Southern Oscillation: 1982-1983 perspectives." Science, 225:713-716.

Shotton, L. R. (1982). "Response of wildlife and farm animals to low-level military jet overflight." The Reporter, 2(6):161-164.

Sluka, S. J., E. L. Besch, & A. H. Smith (1965). "A hydrostatic tester for egg shell strength." Poultry Science, 44:1494-1500.

Stadelman, W. J., & I. L. Kosin (1957). "The effects of sounds of varying intensities on chickens and hatching eggs." Wright Air Development Technical Report 57-87, AD110838. Report by the Poultry Science Department, State College of Washington, for the Wright Air Development Center.

Subcommittee on Animal Response (1970). "An annotated bibliography on animal response to sonic booms and other loud sounds." A report to the Committee on SST-Sonic Boom, National Academy of Sciences. National Research Council.

Teer, J. G., & J. C. Truett (1973). "Studies of the effects of sonic boom on birds." Report by James G. Teer and Company for the Department of Transportation, Federal Aviation Administration. NTIS No. AD-768-853/4.

Whittow, G. C. (1985). "Partition of water loss from the eggs of the Sooty Tern between pre-pipping and pipped periods." Wilson Bulletin, 97: 240-241.

APPENDIX A Summary of Differences Between Exposed and Control Groups of Eggs Exposed to Simulated Sonic Booms and Supersonic Overflights in Previous Studies of Noise Effects

Table A-1: Summary of previous studies exposing eggs to sonic booms.

Study	Breed	No. of Eggs	Fertility	Sonic Boom Exposure	Percent Hatched	Statistical Tests
Keller, 1993 (also Cottereau, 1993)	Rhode-Island x Wyandotte chickens	213	86-97%	Test 1: Control	65.5	Chi-square p >0.05
				Displaced Control	61.5	
				6/day, 18 days, 1 mb, 270 ms	68.0	
				6/day, 18 days, 1 mb, 270 ms	76.8	
		215	85-97%	Test 2: Control	87.7	Chi-square p >0.05
				Displaced Control	85.5	
				6/day, 18 days, 5 mb, 300 ms	94.6	
				6/day, 18 days, 5 mb, 300 ms	80.0	
		209	81-95%	Test 3: Control	74.5	Chi-square p >0.05
				Displaced Control	76.4	
				6/day, 18 days, 15 mb, 300 ms	81.5	
				6/day, 18 days, 15 mb, 300 ms	79.2	
		210	76-97%	Test 4: Control	85.2	Chi-square p >0.05
				Displaced Control	87.7	
				6/day, 18 days, 30 mb, 300 ms	77.8	
				6/day, 18 days, 30 mb, 300 ms	88.9	
Heinemann and LeBrocq, 1965	White Leghorn chicken	360	96-98%	Control (7 days)	79.4	Not significant (test not specified)
		630		Control (17 days)	85.3	
		900		Control (21 days)	86.1	
		900		30/day, 7 days, 3-18 psf	85.1	
		630		30/day, 17 days, 3-18 psf	85.8	
		360		30/day, 21 days, 3-18 psf	88.0	
		900		30/day, last 14 days, 3-18 psf	86.6	
		630		30/day, last 4 days, 3-18 psf	83.4	
Cogger and Zegarra, 1980				Boom simulated with carbide cannon		
	White Leghorn chicken	40x5 replicates	89-91%	1 on day 13, 156.3 dB (flat SPL)	85.1 (se=4.4)	Chi-square p >0.05
		40x5 replicates		1 on day 19, 156.3 dB (flat SPL)	82.3 (se=5.1)	
		40x5 replicates		Control	78.3 (se=6.1)	
		60x2 replicates		1 on day 1, 156.3 dB (flat SPL)	88.0	Chi-square p >0.05
		60x2 replicates		Control	87.5	
Teer and Truett, 1973	Bobwhite quail	250X4	86.4	3/day, 18 days, 2 psf	84.6	Fertility: ANOVA, F=4.69, p <0.05
		250x3	88.8	3/day, 18 days, 4 psf	90.8	
		250x2	87.3	3/day, 18 days, 5.5 psf	77.6	
		250x1	85.3	2/day, 18 days, 2 psf	79.5	
		250x0	82.8	2/day, 18 days, 4 psf	76.6	
		250x1	86.7	2/day, 18 days, 5.5 psf	72.8	Hatchability: ANOVA, F=6.19 p <0.01
		250x2	87.9	1/day, 18 days, 2 psf	82.5	
		250x3	85.9	1/day, 18 days, 4 psf	78.9	
		225x3	85.2	1/day, 18 days, 5.5 psf	76.5	
		250x3	82.9	Control	76.8	